

FFAG Lattice Costs

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Modified Palmer Cost Model

$$\begin{aligned}
 B_{i\pm} &= B_0 \pm B_1 f_R R \\
 R_{o\pm} &= f_R R + t_C |B_{i\pm}| \\
 B_{o\pm} &= B_0 \pm B_1 R_{o\pm} \\
 B_{e\pm} &= \begin{cases} B_{i\pm} & |B_{i\pm}| \geq |B_{o\pm}| \\ B_{o\pm} & |B_{i\pm}| < |B_{o\pm}| \end{cases} \\
 C_{\pm} &= C_{m0} B_{e\pm}^{1.5} R_{o\pm} (L + f_E f_R R) \\
 f_Q &= \frac{|B_{e+} + B_{e-}|}{|B_{e+}| + |B_{e-}|} k_D + \frac{|B_{e+} - B_{e-}|}{|B_{e+}| + |B_{e-}|} k_Q \\
 C_{\text{mag}} &= \frac{1}{2} (C_+ + C_-) \left(\frac{n_0}{n} \right)^{1/3} f_A f_Q \\
 C_{\text{rf}} &= \frac{k_C V G_0}{G} + \frac{k_P V G}{G_0} \\
 C_{\text{lin}} &= C_L L_R
 \end{aligned}$$

- Costs C_{mag} (magnets), C_{rf} (RF), and C_{lin} (linear)
- Central field is B_0 , gradient is B_1
- n magnets, magnet radius is $f_R R$, magnet length is L
- Total installed voltage is V , RF gradient is G
- Ring length is L_R

Modified Palmer Cost Model (cont.)

f_R	1.3	t_C	2 mm
C_{m0}	$22.5 \text{ mPB/T}^{1.5}/\text{m}^2$	f_E	20
k_D	1	k_Q	1.5
n_0	300	f_A	1.5
k_C	30 PB/GV	k_P	26.8 PB/GV
G_0	16 MV/m	C_L	25 mPB/m

- PB is our cost unit the “Palmer Buck”

- Non-Scaling FFAG lattices optimized to same design parameters

Minimum energy	10 GeV
Maximum energy	20 GeV
RF frequency	201.25 MHz
Voltage per cavity	7.5 MV
RF drift length	2 m
Short drift length	0.5 m
Minimum energy tunes	0.35
ΔT per cell	7.12 ps
Normalized acceptance	30 mm
Pole tip fields	7 T

- Compare different lattice types: triplet, doublet, FODO
- Not optimized for cost

Type	FDF	FD	FODO 1 RF	FODO 2 RF
Cells	93	101	113	82
D Length (cm)	128	101	81	99
D Radius (cm)	8.4	6.9	8.0	8.3
F Length (cm)	45	81	60	74
F Radius (cm)	9.5	12.4	14.2	17.8
RF Voltage (MV)	698	758	848	1230
Circumference (m)	481	436	612	470
Magnet cost (PB)	76	78	100	112
RF cost (PB)	45	49	55	80
Linear cost (PB)	12	11	15	12
Total cost (PB)	134	138	170	203

- Magnet costs generally high: re-optimize for cost, probably lower fields

Cost Optimized FFAG Lattices

- Allow magnet lengths to vary, find minimum cost lattice

Type	FDF	FD	FODO 1 RF	FODO 2 RF
Cells		113	127	91
D Length (cm)		135	130	139
D Radius (cm)		8.7	9.7	10.1
D Pole Tip (T)		4.7	4.0	4.8
F Length (cm)		222	213	256
F Radius (cm)		13.6	15.5	19.3
F Pole Tip (T)		2.3	1.9	1.9
RF Voltage (MV)		847	950	1362
Circumference (m)		855	941	722
Magnet cost (PB)		34	33	38
RF cost (PB)		55	62	88
Linear cost (PB)		17	24	18
Total cost (PB)		106	118	144

- Optimum cost substantially reduced from 7 T value
- Optimum seems to favor RF costs higher than magnet+linear.
- Optimum wants lower pole tips on FODO F quads
 - ◆ Larger aperture in F quads
- Pole tips relatively low!
 - ◆ May be able to shorten RF drift a bit